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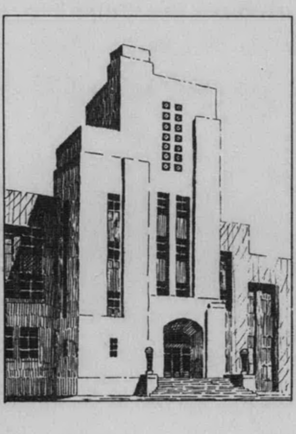
MODEL BASIN

UNITED STATES NAVY

STRAIN DISTRIBUTION ON SPECIMENS
IN A FATIGUE TEST

BY DR. D. F. WINDENBURG



MARCH 1941

REPORT 474

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THE DAVID W. TAYLOR MODEL BASIN
BUREAU OF SHIPS
NAVY DEPARTMENT
WASHINGTON, D.C.

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STRAIN DISTRIBUTION ON SPECIMENS IN A FATIGUE TEST

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STRAIN DISTRIBUTION ON SPECIMENS IN A FATIGUE TEST

SUMMARY

Strain gage measurements were made on two solid plate test specimens of medium steel 5 inches wide by 7/8 inch thick, mounted for routine fatigue tensile test in an endurance testing machine at the University of Illinois, to determine the load distribution over the middle cross section of the specimens.

Both static and dynamic strain measurements were made.

Static strain data were taken with two types of strain gages, Tuckerman optical gages, and metalectric gages of the resistance type. Dynamic strain data were taken with the metalectric gages.

The static and dynamic strain data are compared and conclusions are drawn.

INTRODUCTION

Results of fatigue or endurance tests of large specimens, especially those containing joints, have shown that resistance to continued cyclic load in tension and compression is lower than in small rotating beam specimens of identical material from which stress raisers* have been carefully removed. This lowered resistance is commonly explained as a result of conditions of design and production which make the elimination of stress concentrations difficult and in part impossible. The task has thus become one of evaluating the endurance limit or fatigue strength of assemblies similar to those in service structures.

In this task the conditions of test must be explicitly defined. It is not necessary that the loads occurring in service be duplicated. Rather the uncertainties as to service loads may be left aside for separate study, and attention be focused on the behavior of the assembly under specified load.

In particular, it is necessary to separate features of the behavior of the specimen caused by its own peculiarities from those determined by the manner of load application. Thus, in all endurance testing, special precautions are taken to insure uniform load distribution over the specimen. The variation of load with time throughout the load cycle is another matter of importance.

The purpose of the present test is to obtain the load distribution across the specimen under both static and dynamic loading conditions by direct measurement on the specimen itself when mounted for routine endurance testing.

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* A stress raiser is an irregularity or condition in the test specimen which causes stress concentration and raises the stress intensity above the average stress across the section. Surface cracks and scratches, small holes such as blow holes in welds, and sudden changes in section, are effective stress raisers.

DESCRIPTION OF TESTS

Measurements of strain were made under load in Alternating Load Machine 6, one of the improved type of endurance testing machines in the Arthur Newell Talbot Laboratory of the University of Illinois (1).*

Two different specimens were used, identified as Specimen 1 and Specimen 2, with the dimensions shown in Figure 1. Under static load both Tuckerman and SR-4, type C metalectric strain gages were used; under cyclic load metalectric gages only. Gages were mounted in the parallel portion of the specimen; the Tuckerman and metalectric gages were in series in adjoining sections as shown in Figures 2 and 3. On each specimen there were eight stations, three on each face and one on each edge.

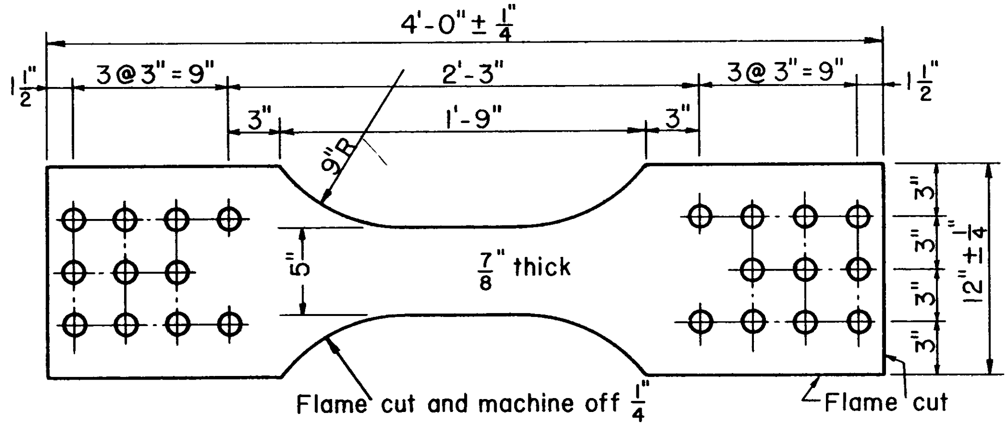

Figure 1 - Detail of Specimen

Simultaneous readings on both types of gages were made under static loads, giving two versions of the distribution under these conditions. Dynamic readings were then taken with the metalectric gages during routine cyclic operation of the machine. This afforded a check on the load setting, a comparison between static and dynamic conditions, and information on the time variation of load in the cycle.

EXPERIMENTAL DETAILS

The manner of transmitting load to the specimen is shown in Figures 25 and 26 of Reference (1). These diagrams are reproduced for convenient reference in Appendix 1. In the present test, load was applied at the rate of 135 cycles per minute. When compressive load is applied, support against buckling is obtained by use of the plates shown in Figure 2, which are clamped to the specimen and mounted with it, but are cut away at midlength so as to expose about 5 inches of the length of the specimen, to which the gages are applied.

The use of Tuckerman gages was not novel, but the application of

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* Numbers in parentheses indicate references at end of this report.

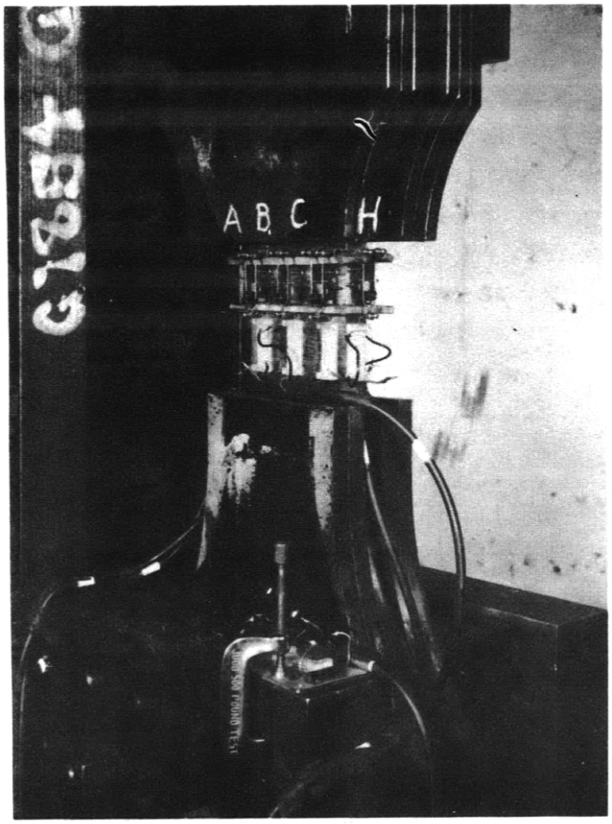


Figure 2 - Assembly of Specimen in Machine, showing Supports against Buckling, and Strain Gages

The Tuckerman gages are in the upper row; the metalectric gages in the lower row

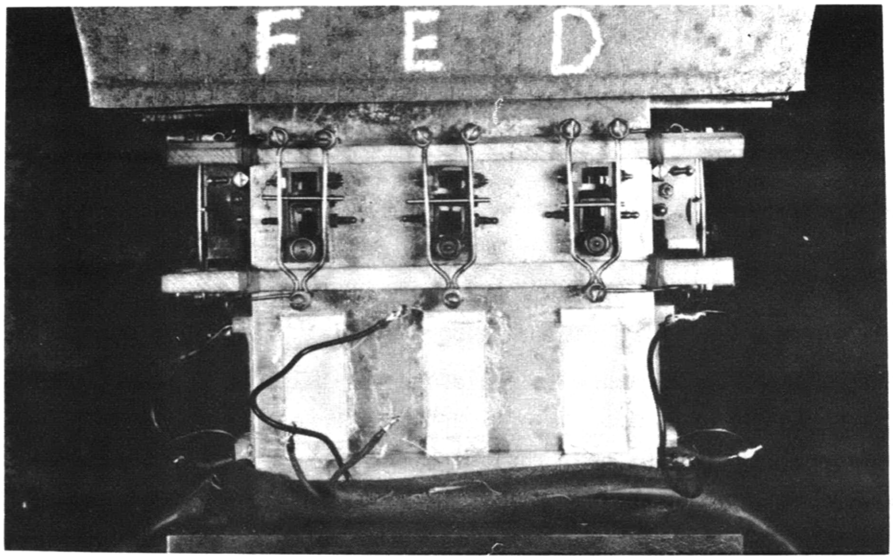


Figure 3 - Detail of Gage Assembly

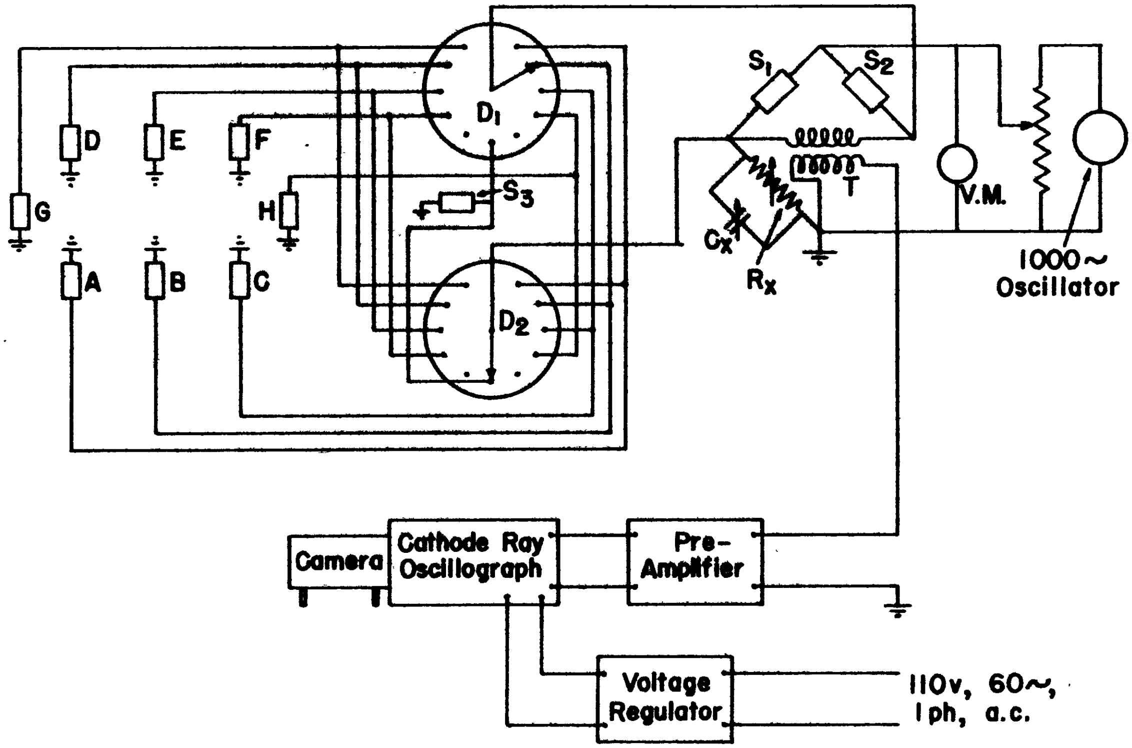


Figure 4 - Wiring Diagram

Notes: 1. A, B, C, D, E, F, G, and H are metalectric strain gages mounted on the specimen.

2. S_1, S_2, S_3 are metalectric strain gages used to complete the Wheatstone bridge. S_3 was mounted on a heavy plate near the specimen, and S_1 and S_2 were mounted in a bridge box.

3. D_1 and D_2 are rotary, 11-position, 2-gang, single-pole switches with the two gangs of each paralleled.

4. C_x is a 50-micromicrofarad variable condenser.

5. R_x is a 100,000-ohm dial resistance box.

6. T is a 500-ohm-to-grid transformer.

7. V.M. is a rectifier-type AC voltmeter.

8. All external connections are made with shielded conductors.

metalectric gages to this problem is new. The metalectric gage consists essentially of a metallic conductor wound as a grid and so arranged that strains in the material to which the gage is attached result in appreciable changes of the electrical resistance of the conductor. For reading static strains, a Wheatstone bridge circuit is used, in which the change in resistance is balanced against standard resistances. For reading dynamic strains, a similar Wheatstone bridge circuit is used, powered with alternating current and provided with an amplifier in the circuit in place of the galvanometer. The bridge is operated by the voltage output of a 1000-cycle oscillator, and the unbalance of the bridge caused by change of resistance of the gages serves to modulate this alternating current signal. The modulated signal is then fed into a cathode-ray oscillograph where it can be observed on a fluorescent screen. The fluorescent image can be photographed when desired. The setup used for dynamic strain measurements in the present test is shown in Figure 4.

Dynamic data from the metalectric gages were read and photographically recorded from the screen of a cathode-ray oscillograph. Accurate synchronization of sweep with signal gave close repetition from cycle to cycle, which facilitated both visual and photographic observation. Sample records are shown in Figures 5a and 5b.

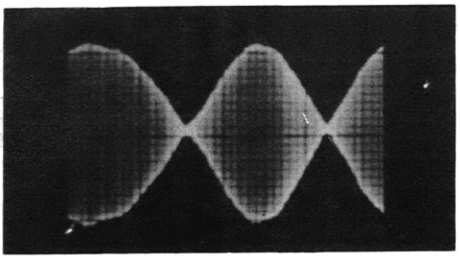


Figure 5a - Cyclic strain from a single station

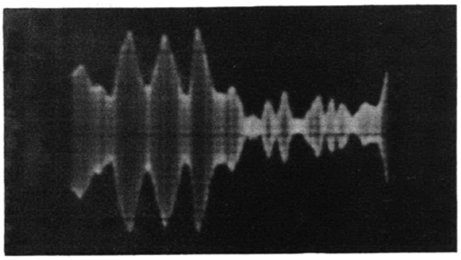


Figure 5b - Difference of strains in two opposite stations

Sample Oscillograph Records of Dynamic Test at 135 Cycles per Minute

The record consists of a modulated carrier wave of 1000 cycles per second, and shows in each case a single load cycle. Such a record does not distinguish between tension and compression, and unless the bridge is balanced exactly at the zero value the two parts of the cycle appear unequal, as seen in Figure 5a. The true course of the record would be found by following the envelope through either of its continuous branches. In the case of Figure 5a, this gives rather accurately a sinusoidal curve. In the case of Figure 5b, which also covers a single operating cycle, the action is more intricate and it is not at all certain whether the envelope crosses the axis or returns to the same side in some cases.

Nonuniformity in stress distribution is indicated by differences in the readings of gages at different stations. In the case of the metalectric gages, a very sensitive indication of strain differences is obtained by connecting two gages in series. When so connected, the uniform membrane strain indicated by the two gages cancels out and the secondary bending strains, if of opposite sign, are added together. Thus, the net signal obtained is proportional to the difference in strain at the two stations. The amplifier gain is then increased as needed to pick up the smaller signals. Such a record is shown in Figure 5b.

TEST PROCEDURE

For cyclic tests, the specimen is mounted in place, the eccentric is set at its mid-position, and the length of the connecting rod is adjusted to obtain zero load (or other mean in the cycle) by dynamometer. The throw of the eccentric is then adjusted so as to give the desired range of load. In these tests the load was set for each run by means of the dynamometer and not by angular setting of the crank. On this type of endurance testing machine, this load adjustment can be made and dynamometer readings can be taken only when the machine is at rest.

The static readings were taken, following the adjustment described. The initial value of load was set at zero, with a range from 15,000 pounds per square inch average tension to 15,000 pounds per square inch average compression. Each cycle of static readings included 5 loads at successive positions of the crank. These were initial zero following compression (CO), maximum tension (MT), zero following tension (TO), maximum compression (MC), and zero following compression (CO), corresponding to initial zero. By subtractions in this cycle, four static increments of load and stress were obtained. The fact that the zero following compression (CO) does not check with the zero following tension (TO) indicates hysteresis in the specimen. It may be that the proportional limit of the material is exceeded slightly at 15,000 pounds per square inch stress, thus giving a hysteresis effect. It is necessary to bear these details in mind in interpreting the results obtained.

In addition to the principal series of observations, data were taken under different conditions, as indicated in the log of the complete tests in Appendix 2. Efforts were made early in the test to use cycles of 25,000 pounds per square inch amplitude, but this range far exceeded the proportional limit of the material and was accordingly reduced. An older machine, Number 1, was used to make a short series of readings with gages set on Specimen 2 at the filleted shoulders as well as in the parallel section.

TEST RESULTS

Seven principal series of static readings were taken. Specimen 1 was given two standard static cycles of load. It was then loaded cyclically as in an endurance test. The static data obtained are shown in Figure 6 in which the solid lines give data from Tuckerman gages and the broken lines data from the metalectric gages.

Specimen 2 had two cycles of static load before an endurance run of about 200,000 cycles, after which two additional cycles of static data were taken. The static results are shown in Figure 7. In Figures 6 and 7 stresses are plotted in the order of the stations as located around the perimeter of the section. These data show substantially identical results in each of the successive cycles, but with significant differences between the tensile and compressive phases.

Stress readings taken during the endurance runs on both specimens are shown in Figure 8, where static stress values averaged from the repeated static cycles are plotted for direct comparison in each case.

The strain data obtained at a stress amplitude of 25,000 pounds per square inch appeared excessive; they must be regarded as preliminary and of no value for the permanent record.

Specimen 2, when placed in Machine 1 and loaded in a static cycle extending from zero to tension only, gave the data shown in Figures 9a, b, and c. No stations

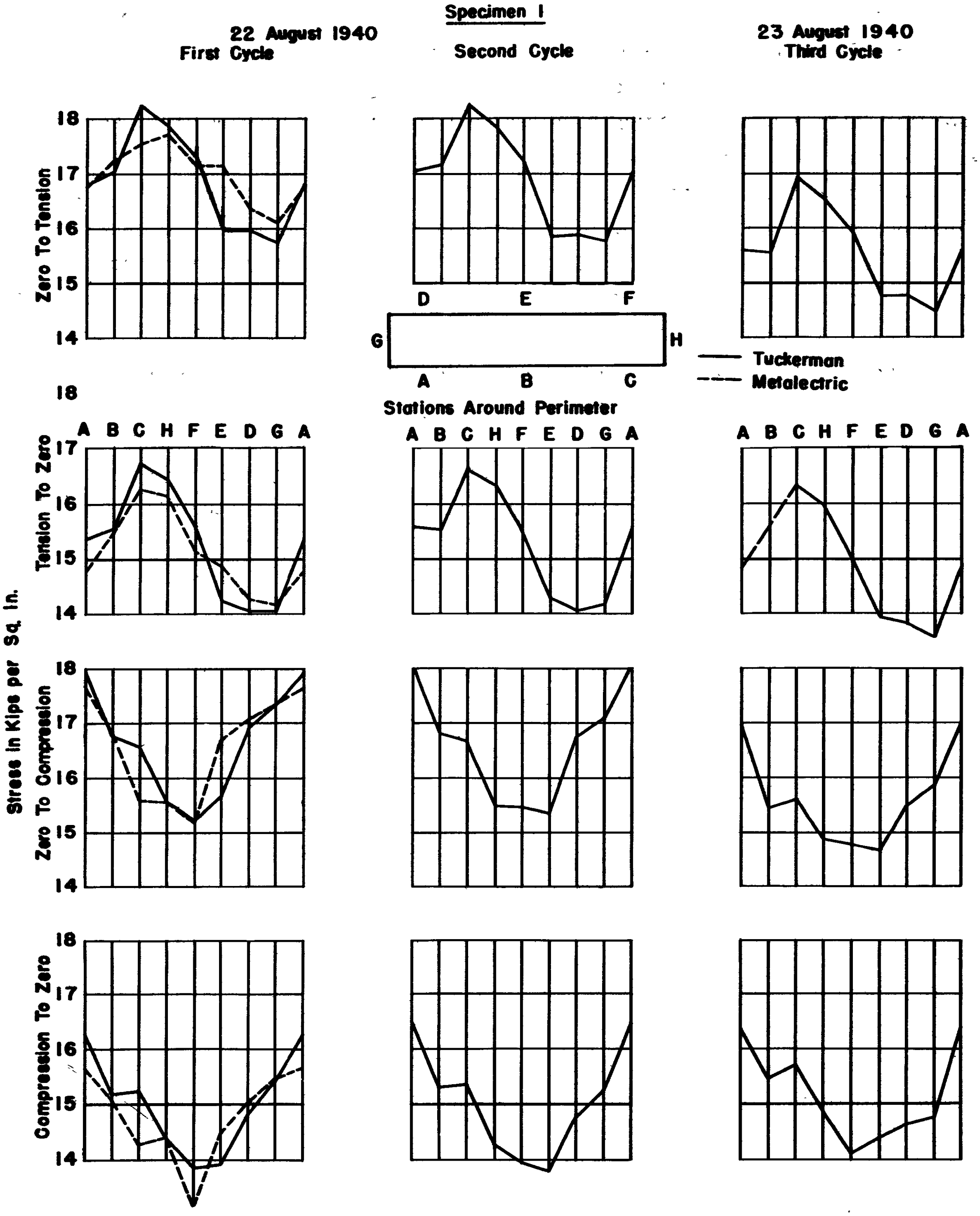


Figure 6 - Variation of Stress around Periphery of Specimen 1

Stress data are from Tuckerman and metalectric strain gages for each successive quarter cycle. The dynamometer was set for a nominal stress of 15 kips per square inch

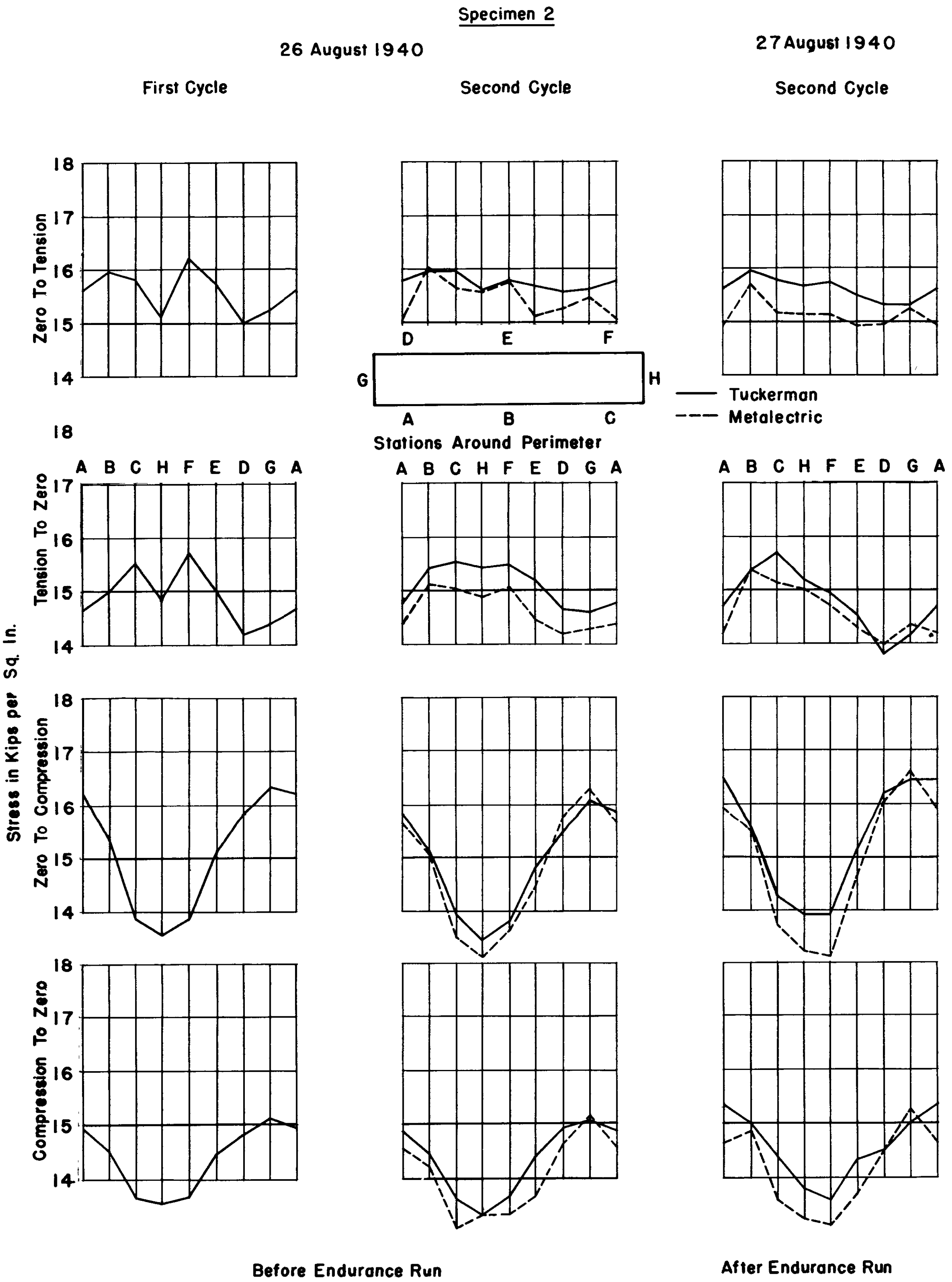
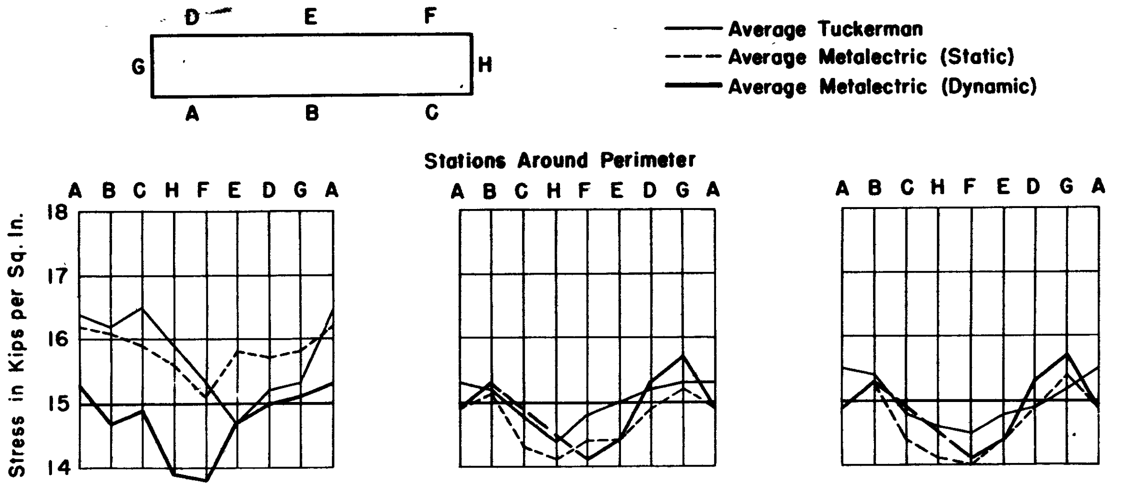


Figure 7 - Variation of Stress around Periphery of Specimen 2

Stress data are from Tuckerman and metalectric strain gages. The dynamometer was set for a nominal stress of 15 kips per square inch



Specimen 1. 23 August 1940

Specimen 2. Static data taken before endurance run

Specimen 2. Static data taken after endurance run

Figure 8 - Comparison of Maximum Static and Dynamic Stress Measurements

were used on the edges of the specimen. No metalectric data were taken, no dynamic loads applied.

DISCUSSION OF TEST RESULTS

The variation of load with time, as shown in Figure 5a, is quite continuous and free from shock such as might reduce the endurance of specimens when tested in this manner. The stress scale in Figure 5b is magnified (in a ratio of roughly 10 times) as compared with Figure 5a, so that the irregularities are not as serious as they seem. Even in Figure 5b, however, the variations are continuous and not abrupt. They are apparently caused by incidental vibrations in the specimen or machine rather than by impact such as would develop, for example, through lost motion on reversal of the load.

The agreement between mechanical and electrical gages as shown in Figures 6 and 7 is within satisfactory limits for work of this kind.

The agreement between static and dynamic stress values, as shown in Figure 8, is none too satisfactory on Specimen 1, but on Specimen 2 it leaves little to be desired. The improvement is attributed to better technique in using the metalectric gages. For Specimen 1, the gages were calibrated only after all strain data had been taken. For Specimen 2 each gage was calibrated immediately after the strain data were taken with that gage.

The test results shown in Figure 8 show that under favorable conditions dynamic stress values do not differ appreciably from static values and that no major correction for inertia effects in the machine need be considered.

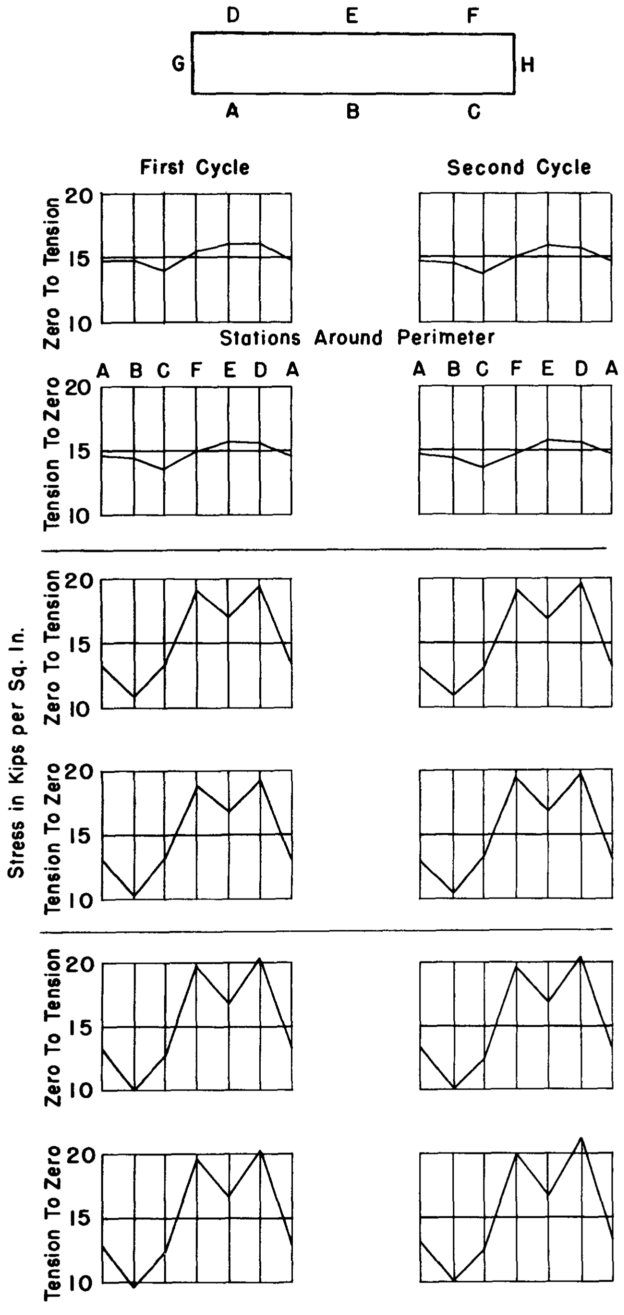


Figure 9a

Gages at

midlength

Figure 9b

Gage stations

at point of

tangency

Figure 9c

Gage stations

1/2 inch above

point of tangency

Figure 9 - Variation of Stress over Cross-Section of Specimen 2 in Machine 1 as Measured by Tuckerman Strain Gages

The cycle is from zero to 15 kips per square inch tension and back to zero. Because of greater departures from the average than in Figures 6, 7, 8, the vertical scale has been reduced in Figure 9

Before the strain data are interpreted, comment on their accuracy is in order. As judged by the agreement between values from the same gage on successive static cycles, discrepancies of 500 pounds per square inch in derived stress values are rare, while agreements within 200 pounds per square inch are common. Comparison of readings from two gages of different type under identical conditions (except at stations in adjacent sections) shows somewhat greater discrepancies, but the maximum is still well under 1000 pounds per square inch and the mean is not over 400 pounds per square inch. As fractions of load increments, these are moderate errors, 5 per cent or less.

Another check on the strain-gage data is afforded by comparison of the average derived stress values with the gross load per unit area as measured by the dynamometer incorporated in the machine, or 15,000 pounds per square inch in each case. This comparison is not entirely legitimate, since the derived stresses depend upon an *assumed* modulus of elasticity, and no stress-strain curves for the specimens are available. The assumed value was 30 million pounds per square inch. This value is probably high and may exceed the actual modulus by more than 5 per cent. The agreement, on the whole, is less satisfactory than that involving strain gages only. For example, the most consistent of all the sets of strain-gage data, at the top of Figure 7, with stress values contained within a range of ±500 pounds per square inch, still shows averages about 500 pounds per square inch higher than the value by dynamometer. Larger discrepancies of this sort may be seen elsewhere in the data and seem to be without relation to the uniformity of stress in the section. If the self-consistency of the strain-gage readings can be accepted as indicating their correctness, the averages taken over the whole section should have rather high validity. It is therefore pertinent to inquire by what sort of action in the machine discrepancies of this sort might be caused.

In order to obtain some light on this point, the data have been replotted in different form so as to show variations at each strain-gage station of stress increments in the various phases of the static loading cycle. The various parts of Figures 10 and 11, in which these results are seen, show a striking uniformity which may be described as follows: At the edge marked G and at adjoining stations the stress follows a cycle of W-form, while at the edge marked H and adjoining stations the form is that of a V.

The cycle of W-form suggests action resembling hysteresis, in which the stress increment on release is smaller than that on application of load, either in tension or compression.

The cycle of V-form suggests buckling in the specimen, since the increment of stress is smaller in the compression than in the tension phase.

When the data are plotted in this way the departure of average stress by gage from the value by dynamometer seems less pronounced. Especially in Specimen 2 the variations are distributed quite equally about the dynamometer value. In

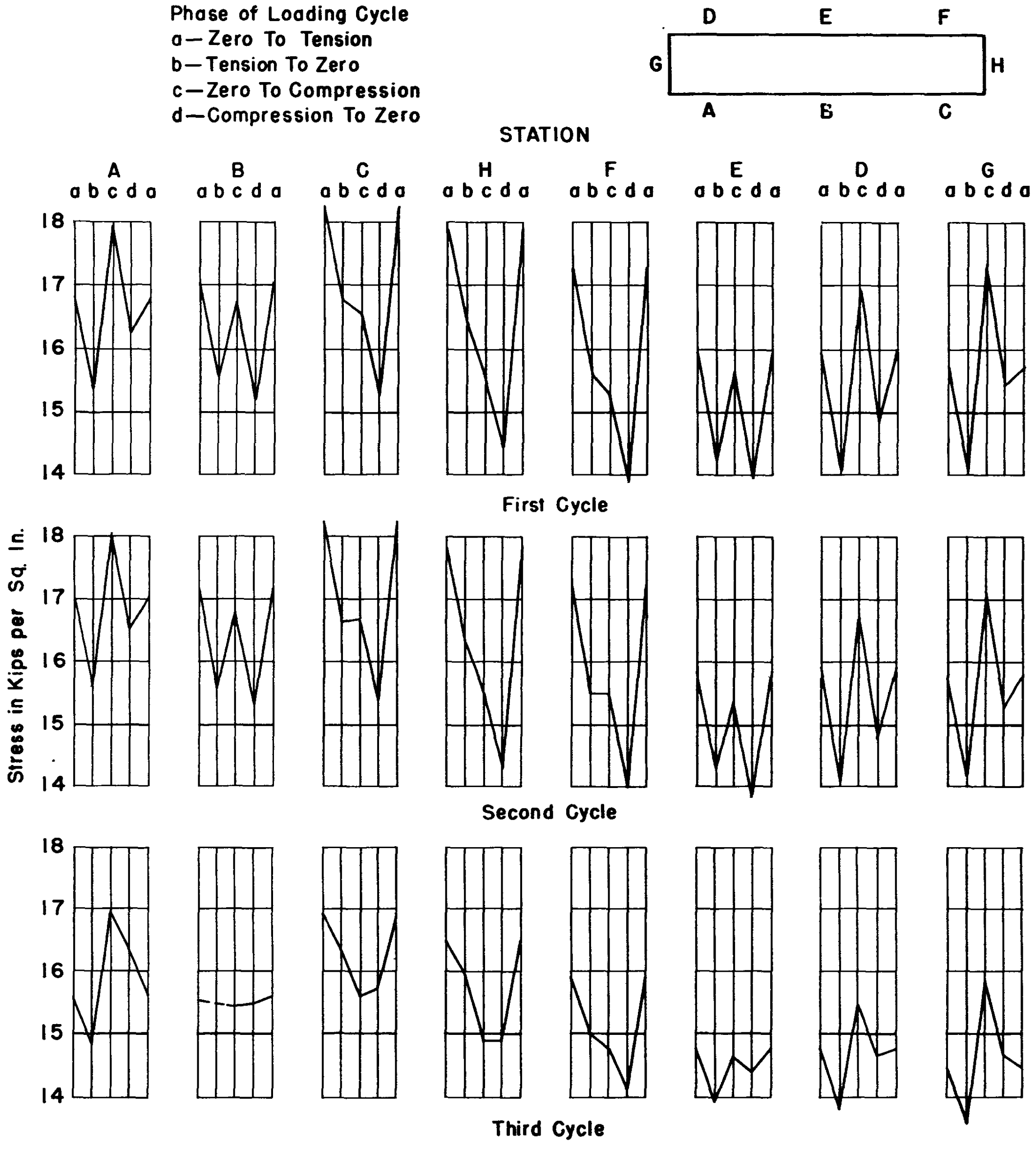


**Figure 10 - Cyclic Variation of Stress Increment at each Station
Specimen 1, Tuckerman Gage Data**

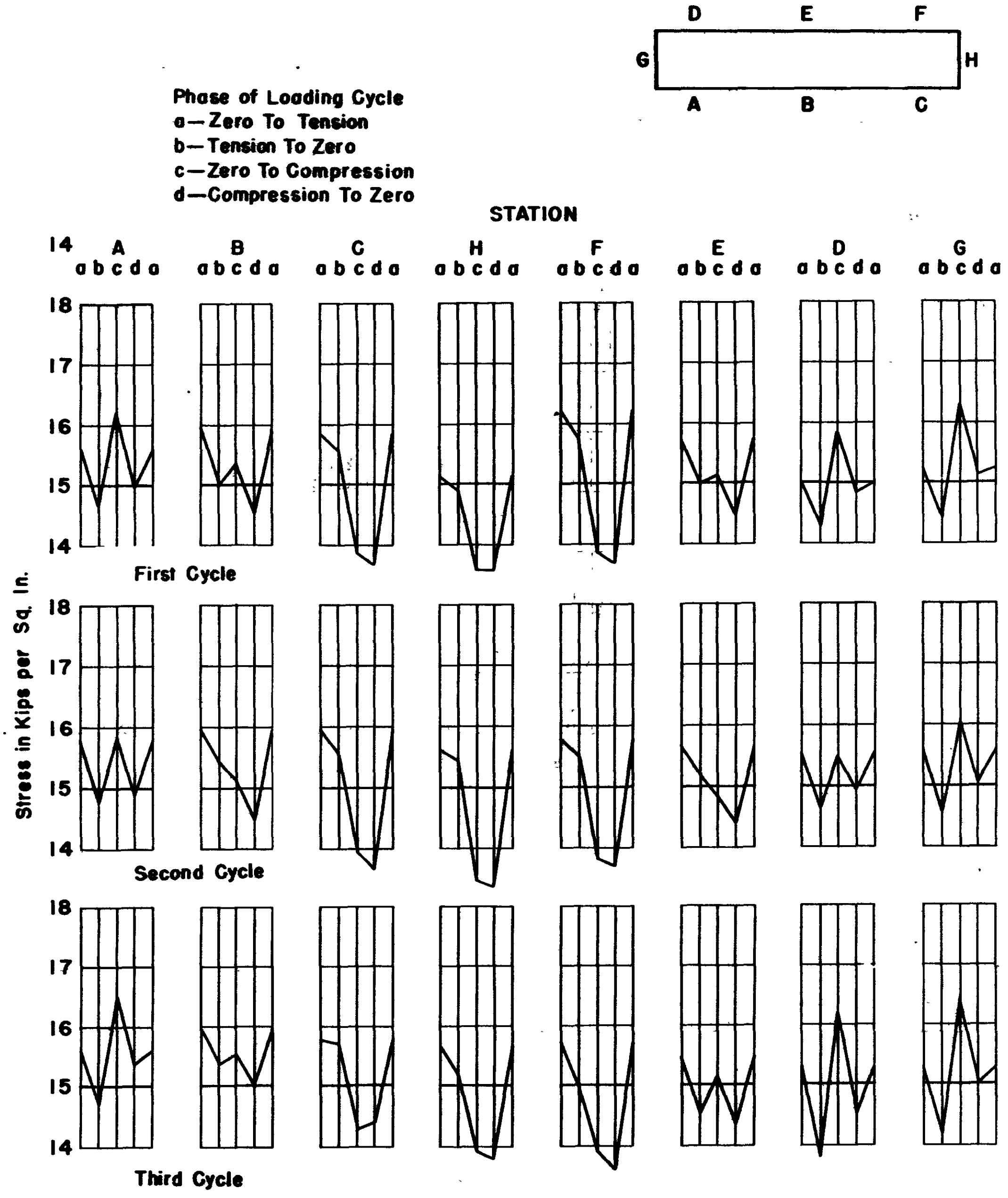


**Figure 11 - Cyclic Variation of Stress Increment at each Station
Specimen 2, Tuckerman Gage Data**

Specimen 1, however, the average stress for stations D, E, and F is distinctly on the high side, and even the average for all stations would be too high by nearly 1000 pounds per square inch. The third cycle for Specimen 1 shows distinct improvement over the others, both in average and in deviations from the average. As previously mentioned, however, it is entirely possible that the major part of this discrepancy results from the use of too high a modulus value in deriving the stress values.

Stress distribution in the section under static load departs from uniformity by considerable amounts. These departures are not to be explained simply as flatwise bending, since there are differences between the readings on the two edges as well as on opposite faces of the specimen. Bending is a large part of it, however, and this is borne out by comparison of the different phases of the cycle, which shows greater deviation from average stress in compression than in tension.

The division of secondary bending stresses into flatwise and edgewise bending can be more clearly seen when the data are plotted as shown in Figures 12 and 13. Here the separation of the stress lines ABC from the stress lines DEF indicates the amount of secondary stress due to flatwise bending, while the slope of the line connecting the points G and H indicates the amount of edgewise bending. Specimen 1 has a fairly large amount of flatwise bending, while Specimen 2 is practically free from it. However, both specimens have a considerable amount of edgewise bending. It will be observed that the slope of the edgewise bending is of different sign for tension than for compression. This probably is due to some characteristic of the loading mechanism and not to eccentric setting of the specimen. If the specimen were loaded eccentrically but along the same line both in tension and compression, the effect would be to increase both the tensile and the compressive stresses by the same amount. In the present tests, the tensile bending stresses increase while the compressive bending stresses decrease. This condition indicates that the point of load application shifted in the time interval between the tension and compression phases of the cycle.

The data taken in Machine 1 on Specimen 2 merit particular attention. It had been found experimentally that practically all solid specimens (no joints) failed at the point of tangency to the parallel middle section. This indicated stress concentration at this point, as might be expected from the shape of the specimen. Accordingly, an attempt was made to get a measure of this stress concentration by taking Tuckerman strain-gage readings at various sections on the specimen. These data were taken on Specimen 2 in Machine 1 while metalectric-gage data were being taken on Specimen 1 in Machine 6. The data taken across the specimen at the point of tangency and 0.5 inch above the point of tangency are plotted in Figures 9b and 9c. They show not only high values of stress concentration at the edges of the specimen, but abnormally high transverse bending stresses. On the other hand, the bending stresses at the midlength of the specimen as shown in Figure 9a are no greater than those for Specimen 1 in Machine 6, shown in Figure 6.

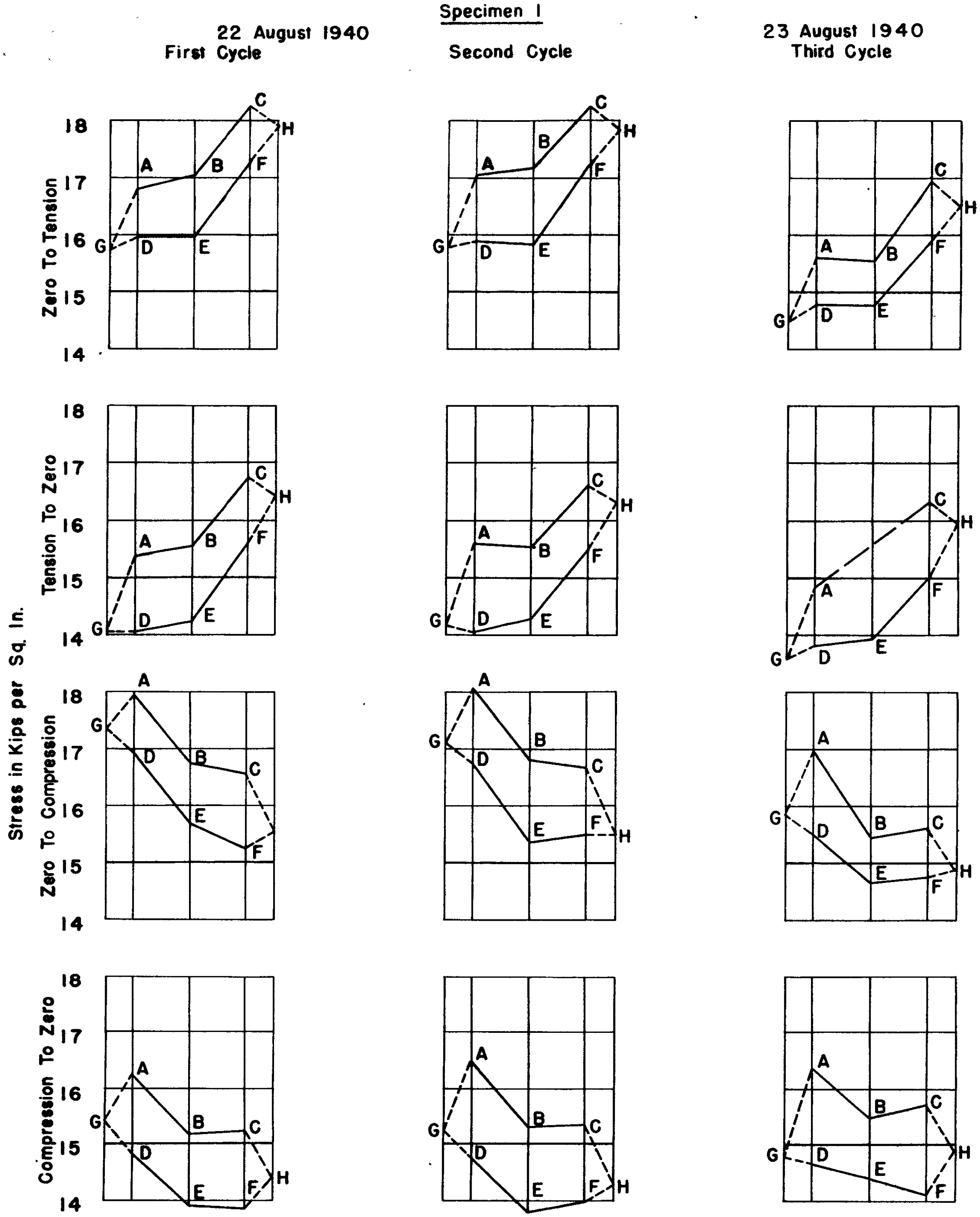


Figure 12 - Variation of Stress over Cross-Section of Specimen 1

The data used in Figure 6 are here plotted to show the division of secondary stresses into flatwise and edgewise bending. The distance between the lines ABC and DEF indicates the amount of flatwise bending; the slope of the line connecting G and H indicates the amount of edgewise bending

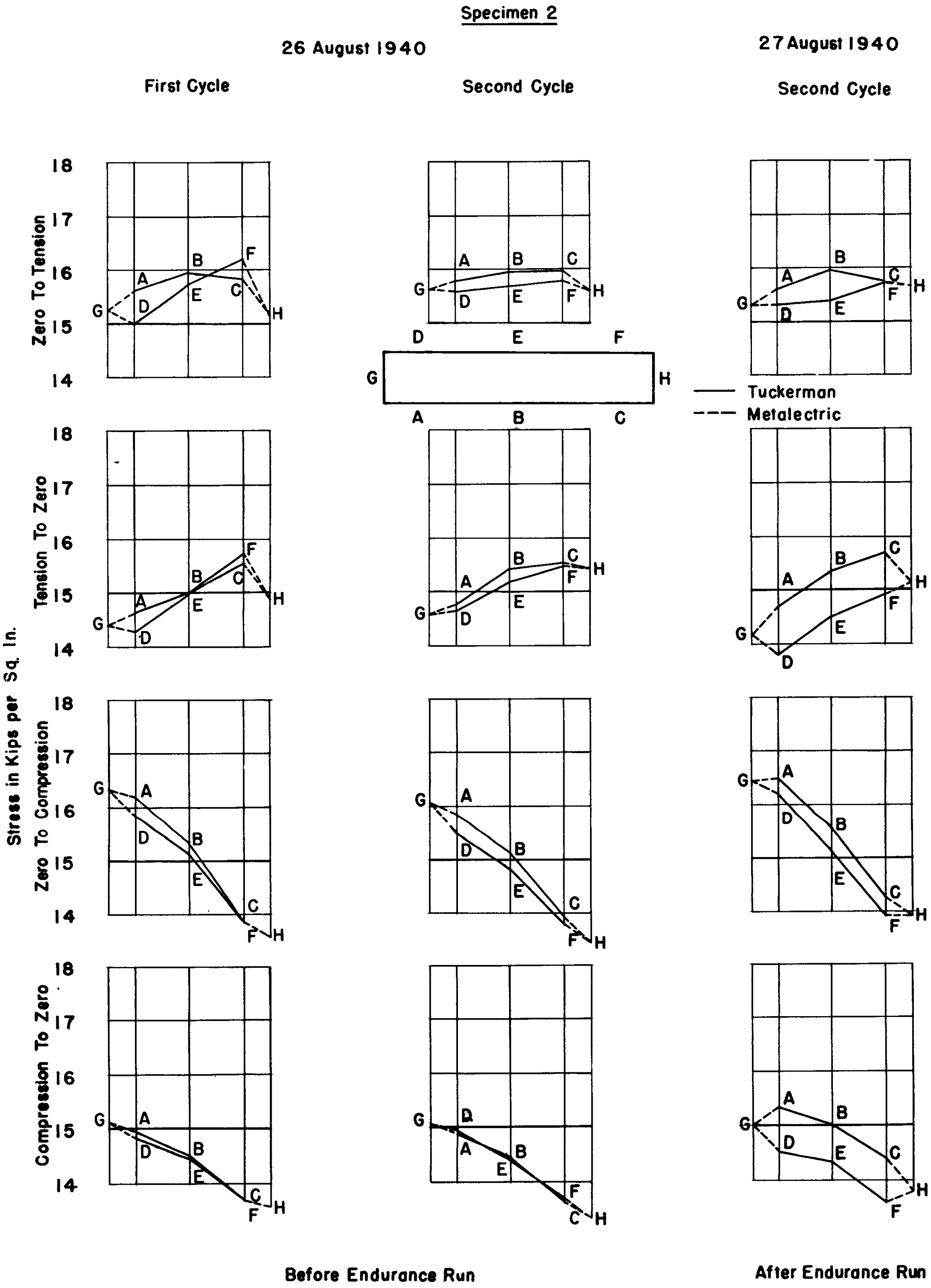


Figure 13 - Variation of Stress over Cross-Section of Specimen 2

The data used in Figure 7 are here plotted to show the division of secondary stresses into flatwise and edgewise bending. The distance between the lines ABC and DEF indicates the amount of flatwise bending; the slope of the line connecting G and H indicates the amount of edgewise bending

At first thought, it would be expected that the bending stresses would be even greater at midlength. The fact that they are smaller there might be explained by a cocking of the upper wedge block, which would load the specimen as a cantilever with maximum moment at the upper end. The condition might be explained also if there were a point of inflection at the midlength. Such a condition can be realized in practice by constraining the clamped loads at the two ends of the specimen to move parallel to each other but offset by a definite amount. Such might well be the condition existing in this machine and other machines of this type. It is a condition that cannot be detected by taking strain measurements at midlength of the specimen only. Additional strain data taken at the other end of the test specimen would no doubt have answered these questions.

Even if this high bending stress were eliminated by proper alignment, there still would remain a stress concentration of about 10 per cent above the mean value at midlength due to the shape of the specimen alone. The only way this concentration can be reduced is by making the transition more gradual. Unless overall length were increased this would result in a decreased length of parallel section, but such a decrease is probably acceptable. In fact, it might even be desirable to increase the radius of curvature until there is no parallel section.

These suggestions are based on admittedly meager data, to which only incidental attention was given during the test. Additional study of misalignment by offset, perhaps by the methods used in the present tests, should shed more light on this point.

CONCLUSIONS

Either Tuckerman or metalectric strain gages can be used to determine the static stress distribution over large fatigue test specimens with good accuracy. The metalectric gages can be used to good advantage to determine the dynamic stress distribution.

The maximum departure of stress from the average value is about 10 per cent. If this departure is known by the operator, it can be reduced by adjustments of the machine.

The cyclic load on a specimen is approximately the same in distribution and intensity as that applied under static conditions. Superimposed dynamic stresses due to impact or inertia effects appear to be absent in the type of machine used in these tests.

RECOMMENDATIONS

It is recommended [1] that similar static tests be made with Tuckerman strain gages on all alternating-load testing machines used in routine fatigue tests for the Bureau of Ships; [2] That static tests be made at the David W. Taylor Model Basin to investigate the effect of fillet shape on stress concentration in solid fatigue-test specimens.

PERSONNEL

This test is the work of D. F. Windenburg and W. J. Sette of the Applied Mechanics Section, David W. Taylor Model Basin. The data were calculated by L. D. Anderson of the staff.

REFERENCE

(1) "Fatigue Tests of Riveted Joints," by W. M. Wilson and F. P. Thomas, Bulletin No. 302, University of Illinois Experiment Station, 1938.

APPENDIX 1

The following description and diagrams of the type of alternating-load machine used in these tests are taken from pages 44 to 49 of Reference (1).

"The essential features of the machine are shown in Figure 25. The force that produces the stress in the specimen originates in the variable-throw eccentric and is measured by the dynamometer. The force is multiplied by the I-beam lever, which has a multiplication ratio of 18. The specimen is attached to the pulling heads by means of turned bolts made of high-strength steel, the turned bolts being 1/32 in. smaller than the holes in the head of the specimen. The two side plates that form each pulling head are spaced a considerable distance apart so as to straddle the bottom flange of the I-beam lever. Two fills were placed between the specimen and each side plate. One, a thick fill, was welded to the side plate so as to prevent excessive flexure on the bolts. The other, a thin one, several of different thicknesses being available, was used to adjust the pulling head to specimens of various thicknesses.

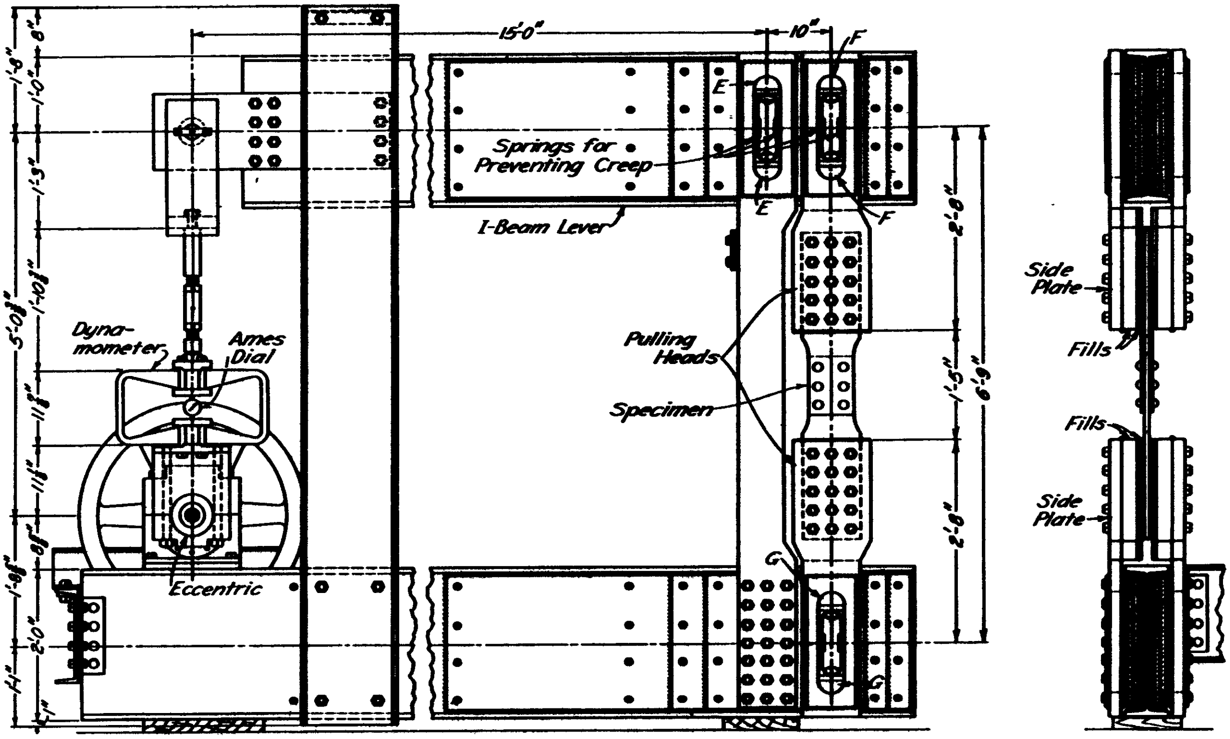


Figure 25 - Machine for Fatigue Tests of Riveted Structural Members

"Bearings were provided at E which would support the I-beam lever in such a manner as to provide for free angular motion. This was necessary because the up-and-down motion of the outer end of the beam produced by the eccentric causes the beam to rotate about a horizontal axis. Similar bearings were provided at F and G, the outer ends of the pulling heads. These give the specimen freedom from angular restraint, which is necessary as otherwise a moment would be induced in the specimen and the unit stress at the section of failure would be unknown. The load to which these bearings are subjected is so large and the bearings at E and F are so close together that the usual types of bearings are not suitable. The special bearing that was devised to meet these unusual conditions is shown in Figure 26 and described in the following paragraph.

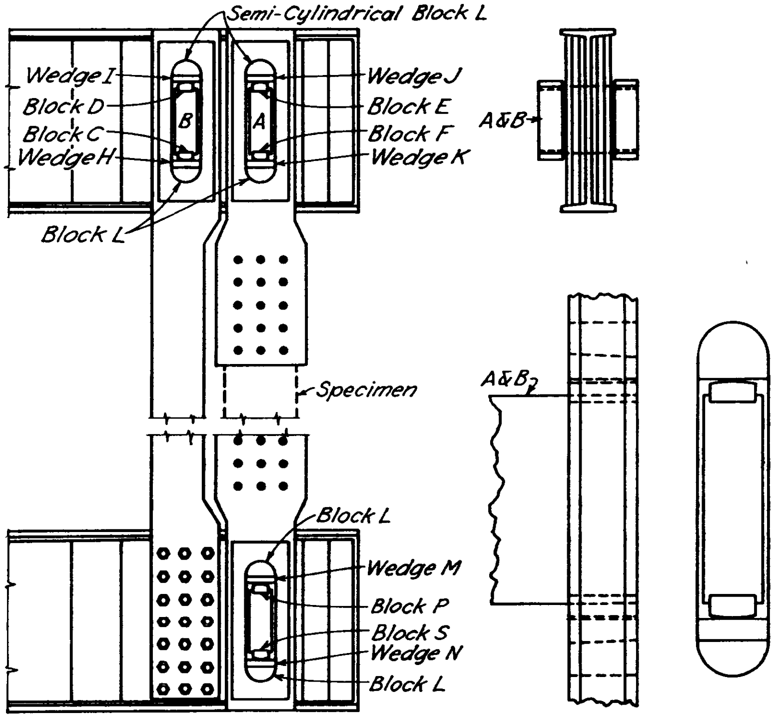


Figure 26 - Bearing Supporting I-Beam Lever and at Outer Ends of Pulling Heads of Fatigue Machine

"The bars A and B are a press fit in the reinforced web of the I-beam lever and project a little more than 3 in. from each side of the web. The segmental blocks C, D, E and F are hardened tool steel ground to a smooth cylindrical surface, and they are attached in such a manner that they can be removed, refinished, and replaced. The wedges H, I, J and K are also of hardened tool steel with ground plane surfaces and they, likewise, can be removed for refinishing. The blocks and wedges are on both the near and the far side of the lever. The wedges are supported on the steel semi-cylindrical blocks L that have inclined plane surfaces, which, in conjunction with the wedges, provide a means for adjusting the vertical distance between the two wedges, such as I and H, that constitute a pair. When the left-hand end of the I-beam lever moves down, putting the specimen in tension, the segmental block C rolls on the wedge H, and the segmental block E rolls on the wedge J. Because there is pressure between C and H there will not be, with proper adjustment of the wedges, pressure between D and I, and sliding can take place. Likewise sliding can take place between F and K as E rolls on J. When the outer end of the beam is pushed up by the eccentric, putting the specimen in compression, D rolls on I and F rolls on K, and, at the same time, C slides on H and E slides on J. For tests for which there is no reversal of stress, the blocks-and-wedges D and I and F and K may be omitted.

"The line contact between the segmental blocks C, D, E, and F and the wedges H, I, J and K is the contact between a horizontal cylinder and a horizontal plane and lies in a vertical plane through the axis of the cylinder for all positions of the lever. For this reason the rotation of A and B as the left-hand end of the I-beam lever moves up and down does not affect the multiplication ratio of the lever.

"The dynamometer is a closed rectangle of steel machined from the solid. An Ames dial indicates the deflection of the long sides, as indicated in Figure 25. The dynamometer was calibrated after it had been subjected to several thousand cycles and again after several million cycles. The change in the calibration constant was so small that further calibrations appeared unnecessary. The deflection of the dynamometer for a variation of the load on the specimen from 200 000 lb. tension to 200 000 lb. compression was approximately 0.07 in. and the corresponding vertical movement of the outer end of the lever was approximately 7 in."

APPENDIX 2

LOG OF TESTS

20 August 1940. Prepared Specimen 1 for test and mounted it in Machine 6. Mounted metalectric gages and set up apparatus.

21 August 1940. Mounted Tuckerman gages, completed set-up of apparatus, and made preliminary static tests at stress amplitudes of 25,000 pounds per square inch.

22 August 1940. Reduced stress amplitude to 15,000 pounds per square inch. Took data for two cycles of static strain with both Tuckerman and metalectric gages.

23 August 1940. Took one more cycle of static data and then removed Tuckerman gages. Operated machine and took complete set of dynamic data with metalectric gages. Obtained both visual and photographic data from oscillographic records. Calibration data were taken after run had been completed. Machine was left running all night.

24 August 1940. Made visual observations on metalectric gages while the machine was still running. Mounted Tuckerman gages on Specimen 2 in Machine 1. Took static strain data at parallel section and point of tangency. Mounted Specimen 2 in Machine 6, and mounted metalectric gages.

26 August 1940. Mounted Tuckerman strain gages and took two cycles of static gage data. Machine was then started and run all night with both types of gages in position.

27 August 1940. Took dynamic strain data, calibrating each gage as soon as data had been taken. The machine was then stopped and static data were taken with both types of gages. The load was then increased to 25,000 pounds per square inch and the amplitude and form of the load curve were observed.